BIOLOGICAL NUTRIENT REMOVAL OF PALM OIL MILL EFFLUENT (POME) USING HYBRID SEQUENCING BATCH REACTOR (H-SBR)

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To my beloved father & mother, my siblings

&

Husband

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“In the name of God, the most gracious, the most compassionate”

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ABSTRACT

Recently, one of the alternative technologies applied in treating POME is the combined anaerobic-aerobic system such as conventional sequencing batch reactor (SBR). However, the conventional SBR requires sophisticated technology with high maintenance and multiple tanks. In this study, a modified SBR system with combination of both anaerobic and aerobic condition, named as hybrid sequencing batch reactor (H-SBR), was introduced which combine all of the treatment phases (fill, react, settle, decant, idle) in a single tank. The experiment was set up using automatic bioreactor with a combination of 50 % inoculum (anaerobic/aerobic) and in fresh POME. Preliminary study on single aerobic and anaerobic conditions in treating POME was carried out to investigate combination of anaerobic-aerobic sequences for the best biological nutrient removal of POME and the optimum operational sequence of the lab-scale H-SBR system. The hydraulic retention time (HRT) was 12 hours consisting of 11 hours reaction, 20 minutes filling, 10 minutes settling and 20 minutes discharging. The priority was for the removal of COD, nitrogen and phosphorus. It consisted of 6 different types of sequences where three of them were initiated by anaerobic condition, name as Anae and the other three were initiated by aerobic condition, named as Aerob. From all of the experiments, Anae2 (8 hours anaerobic-3 hours aerobic) results showed that the optimum removal efficiencies were 92.7 %, 94.6 %, and 77.9 % for biological nitrogen removal (BNR), COD removal and biological phosphorus removal (BPR), respectively. Optimization experiment was done with HRT was 20 hours for reaction (8 hours anaerobic, 3 hours aerobic, 8 hours anaerobic) and the removals of BNR, COD and BPR achieved were 95.0 %, 94.1 % and 97.8 % respectively.

ABSTRAK

Baru-baru ini, salah satu teknologi alternatif yang digunakan dalam merawat POME adalah gabungan sistem anaerobik-aerobik seperti *Sequencing Batch Reactor* (SBR). Walau bagaimanapun, SBR konvensional memerlukan teknologi canggih dengan penyelenggaraan yang tinggi dan tangki berganda. Dalam kajian ini, sistem SBR diubahsuai dengan gabungan kedua-dua keadaan anaerobik dan aerobik, yang dinamakan sebagai *Hybrid-Sequencing Batch Reactor* (H-SBR), telah diperkenalkan yang menggabungkan semua fasa rawatan (isi, bertindak balas, penetapan, pelepasan, terbiar) tangki tunggal. Eksperimen itu dibina menggunakan bioreaktor automatik dengan gabungan inokulum 50% (anaerobik / aerobik) dan POME segar. Kajian awal terhadap keadaan aerobik dan anaerobik tunggal dalam merawat POME telah dijalankan dahulu untuk menyiasat kombinasi urutan anaerobik-aerobik untuk penyingkiran terbaik biologi nutrien POME dan urutan optimum operasi sistem makmal-skala H-SBR. Masa tahanan hidraulik (HRT) adalah 12 jam yang terdiri daripada 11 jam reaksi, 20 minit pengisian, 10 minit pemendakan dan 20 minit pelepasan. Keutamaan adalah untuk penyingkiran COD, nitrogen dan fosforus. Ia terdiri daripada 6 jenis urutan yang mana tiga daripada mereka telah dimulakan oleh keadaan anaerobik, dinamakan sebagai Anae dan tiga yang lain telah dimulakan oleh keadaan aerobik, yang dinamakan sebagai Aerob. Daripada semua eksperimen, keputusan Anae2 (8 jam anaerobik-3 jam aerobik) menunjukkan bahawa kecekapan penyingkiran yang optimum adalah 92.7%, 94.6%, dan 77.9% bagi penyingkiran nitrogen biologi (BNR), penyingkiran COD dan penyingkiran fosforus biologi (BPR). Eksperimen pengoptimuman telah dilakukan dengan HRT adalah 20 jam untuk tindak balas (8 jam anaerobik, aerobik 3 jam, 8 jam anaerobik) dan penarikan balik BNR, COD dan BPR yang dicapai ialah 95.0%, 94.1% dan 97.8%.

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LIST OF ABBREVATIONS

Ag_2SO_4	-	Silver Sulfate
AN	-	Ammonical Nitrogen
AOP	-	Advanced Oxidation Processes
APHA	-	American Public Health Association
BNR	-	Biological Nitrogen Removal
BOD	-	Biological Oxygen Demand
BPR	-	Biological Phosphorus Removal
CO_2	-	Carbon Dioxide
COD	-	Chemical Oxygen Demand
CPO	-	Crude Palm Oil
DO	-	Dissolved Oxygen
DOE	-	Department of Environment
EVA	-	Evaluation Institute
EWRI	-	Environmental and Water Resource Institute
GHG	-	Green House Gasses
H^+	-	Hydrogen ion
$HgSO_4$	-	Mercury (II) Sulfate
HRT	-	Hydraulic Retention Time
H-SBR	-	Hybrid Sequencing Batch Reactor
$K_2Cr_2O_7$	-	Potassium Dichromate
MBR	-	Membrane Batch Reactor
MLSS	-	Mixed-Liquor Suspended Solid
MLVSS	-	Mixed-Liquor Volatile Suspended Solid
MPOB	-	Malaysia Palm Oil Board
N	-	Nitrogen

NH_4-N	-	Ammonia
NO_2^-	-	Nitrite ion
NO_3^-	-	Nitrate ion
NO_3-N	-	Nitrogen Nitrate
O_2	-	Oxygen
OH	-	Hydroxide
ORP	-	Oxidation Reduction Potential
P	-	Phosphorus
PAOs	-	Polyphosphate-accumulating Organisms
PHB	-	Polyhydroxybutyrate
PO_4-P	-	Phosphate
POME	-	Palm Oil Mill Effluent
RBOM	-	Rapidly Biodegradable Organic Matter
SBR	-	Sequencing Batch Reactor
SO_2	-	Sulfur Oxide
SRT	-	Sludge Retention Time
SS	-	Suspended Solid
STP	-	Sewage Treatment Plant
TKN	-	Total Kjeldahl Nitrogen
TN	-	Total Nitrogen
TS	-	Total Solid
TSS	-	Total Suspended Solid
USEPA	-	United States Environmental Protection Agency
VFA	-	Volatile Fatty Acids
VSS	-	Volatile Suspended Solid

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Malaysia is one of the largest producer and exporter of palm oil in the world in 2006 (Ahmad *et al.*, 2003). In 2007, palm oil exports increased to 15.8 million tonnes (50%) of total world exports (Malaysia Palm Oil Board (MPOB), 2008). Besides, this crucial economic activity had generated an enormous amount of liquid effluent from the milling processes (Salmiati, 2008). Hence, the increase number of mills will create more environmental problem. Large quantities of water are used during the extraction of crude palm oil from the fruit while 50 % of the water results as palm oil mill effluent (POME). It is estimated that for each tonne of crude palm oil produced, 5 to 7.5 tonnes of water will end up as palm oil mill effluent (POME). According to Salmiati (2008), it has been reported that for every tonne of crude palm oil (CPO) produced, about 3.5 m^3 of POME is generated. This means that with 500 palm oil mills, it can produce more than 15 million tonnes of CPO annually. Based on previous study, it was reported that about 50 million m^3 of POME produced from the palm oil industry (Gressel and Hoh, 2005).

Due to the environmental impact, a proper treatment plant is needed to reduce the pollutant before being discharged into the environment. Therefore, various methods of POME treatment are applied such as tank digestion and facultative ponds, tank digestion and mechanical aeration, decanter and facultative ponds; anaerobic digestion and facultative ponds, and development of new activated sludge technologies (sequencing batch reactor (SBR), membrane batch reactor (MBR), and aerobic granulation and cosmo-balls. The adsorption treatment of POME using a boiler fly ash is also being applied recently (Igwe *et al*., 2010).

1.2 Problem Statement

Raw POME has high biochemical oxygen demand (BOD) which reaches about 100 times higher than BOD obtained in sewage. The total BOD loading generated is approximately 1560 tonnes per day, equivalent to the domestic sewage generated by a population of 31.2 million people. Furthermore, POME can also cause serious environmental hazards due to its BOD and chemical oxygen demand (COD) if not properly treated.

Conventional ponding process has been an ineffective method to reduce the biological and chemical constituents of POME. Even though it is relatively simple and reliable, it produces large amount of sludge and takes up large land area. The anaerobic digester that has been applied in anaerobic ponding system generates harmful and odour gaseous such as sulfur dioxide (SO_2) along with greenhouse gaseous emission (methane (CH_4) and carbon dioxide (CO_2). These gases will cause global warming, climate change and danger to public health while facultative ponding systems produce scum and CO_2 as by-product of biological reaction.

Since the sequencing batch reactor (SBR) is well-known as an improvement of activated sludge technology for wastewater treatment since 1920s, it was widely applied in treating both municipal and industrial wastewater. The improvements in aeration devices and controls have allowed SBRs to successfully compete with conventional activated sludge systems. However, conventional SBR requires higher level of sophistication (compared to conventional systems), especially for larger systems, usage of timing units and controls and the needs of large area (Lahlou and Matthews, 2003).

Currently, biological nutrient removal (BNR) that is widely applied in SBR for POME treatment system in Malaysia because it offers green technology due to less pollution production, limited usage of chemicals, low maintenance cost and more environmental friendly. In the BNR reaction, carbon (obtained from CO_2) is utilized for cell growth due to biological process and caused less emission of greenhouse gas. However, application of the process in industry required the usage of multiple tanks to complete all the treatment phases. It also has a lot of operational problem such as effluent did not meet requirement, malfunction of treatment units, break down of equipment and excess consumption of energy, chemicals and human power. Therefore, a new improved SBR with some modifications named as hybrid sequencing batch reactor (H-SBR) was proposed in this research because of its ability to combine different treatment phases in a single tank (Da Costa *et al*., 2008).

1.3 Objectives of the Study

The objectives of the study are:

i. To treat POME using single aerobic and anaerobic conditions
ii. To investigate combination anaerobic-aerobic sequences for the best biological nutrient removal of POME.

iii. To determine the optimum HRT of lab- scale H-SBR

1.4 Scope of Study

This study was focused on investigating of the best condition of H-SBR in lab-scale in treating POME. The H-SBR was introduced as modified conventional batch system using the concept of complete-mixed fed reactor and carried out the best operation sequence for higher treatment efficiency, environmental friendly management, low maintenance and cost-effective. The experiment was initiated by inoculating the microorganisms in three conditions which are anoxic, anaerobic and aerobic. The process was conducted until stable state was achieved. Then, the microorganisms was used during the operation of the lab-scale H-SBR while the optimum condition was determined by selecting the best performance in biological nutrient removal of phosphate, nitrate, total nitrogen, COD and BOD.

1.5 Significance of Study

Therefore, H-SBR has been proposed as a modification of SBR to overcome weaknesses in the system. For that purpose, several palm oil industries in the Johor region has been chosen in this research to examine the specification of their existing treatment plants. Besides, the findings obtained from the lab-scaled H-SBR can be used to enhance the existing treatment efficiency and suggests some modification that was needed. Furthermore, H-SBR is aimed to overcome the problem by offering minimum land acquisition in treatment plant as well as the effective treatment method would gain economical benefits to the local industries.

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